

Genetically Engineered Crops for Pest Management in U.S. Agriculture

Farm-Level Effects

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Introduction

Use of crops genetically engineered with traits for pest management has risen dramatically since their commercial introduction in the mid-1990's. Compared with traditional plant selection and breeding methods, genetic engineering reduces the time to identify desirable traits and allows a more precise alteration of a plant's traits. Seed developers are able to target a single plant trait without the unintended characteristics that may occur with traditional breeding methods. The most widely used pest management traits are herbicide tolerance and insect resistance. Crops having herbicide-tolerant traits permit farmers to use herbicides that offer more effective weed control. Insect-resistant crops containing a gene derived from the soil bacterium *Bacillus thuringiensis* (Bt) produce their own toxin to protect the entire plant from certain insects. (See box, "Agricultural Biotechnology," for definitions of terms.)

Seed companies and scientists claim that herbicide-tolerant and insect-resistant crops offer more effective options for controlling pests, reduce chemical pesticide use with consequent savings in pesticide costs, and increase crop yields. Some of the arguments put forth in support of these technologies are:

- ◆ Herbicide-tolerant genes allow crops to resist effective herbicides that previously would have destroyed the crop along with the targeted weeds. Although farmers using herbicide-tolerant crops continue to use chemical herbicides, these herbicides may be used at lower application rates, require a smaller number of

applications, and may be more benign than herbicides required for crops without the herbicide-tolerant genes.

- ◆ Farmers using Bt crops can reduce insecticide costs by discontinuing or decreasing applications of chemical insecticides targeting certain insects susceptible to Bt such as European corn borer and the cotton bollworm. However, Bt crops may still require farmers to use insecticides to treat other pests. Farmers planting Bt crops benefit from decreased dependence on weather conditions affecting the timing and effectiveness of insecticide applications because the Bt toxin remains active in the plant throughout the crop year. These improvements reduce losses to pests, leading to higher yields.

Despite the promise of benefits, environmental and consumer concerns may temper acceptance of agricultural biotechnology in the United States and globally (see box, "Environmental and Other Concerns"). Moreover, although farmers may experience decreased pesticide costs and higher gross revenues from herbicide-tolerant and insect-resistant crops, there is a cost. Genetically engineered seed costs more than traditional seed, and, in addition, farmers are usually charged a fee to cover the development of the technology (technology fee). A threshold infestation level is thus required for farmers to obtain economic benefits from adopting herbicide-tolerant and insect-resistant crops. The expected benefits from adopting these varieties greatly depend on infestation levels, since the associated pesticide use and yield advantages of the new vari-

Agricultural Biotechnology: Basic Concepts and Definitions

“For thousands of years, genes have been manipulated empirically by plant and animal breeders who monitor their effects on specific characteristics or traits of the organism to improve productivity, quality, or performance. A basic understanding of how traits are transmitted was formed by Gregor Mendel in the 19th century. His experiments and concepts showed that traits were controlled by units of heredity called genes. Extensions of his work led to the formation of applied genetics and breeding programs. The physical and chemical nature of genes remained unknown until the 1950s when James Watson and Francis Crick discovered that genes consists of a chemical known as DNA (Deoxyribonucleic acid). DNA contains the information to control the synthesis of enzymes and other proteins that perform the basic metabolic processes of all cells. Each gene is a specific DNA sequence, and more than 100,000 different genes are found in a higher plant or animal species. This total set of genes for an organism (referred to as the nuclear genome) is organized into chromosomes within the cell nucleus. The process by which a multicellular organism develops from a single cell through an embryo stage into an adult is ultimately controlled in the genetic information of the cell and by interaction of genes and gene products with environmental factors” (Vodkin).

Agricultural biotechnology is a collection of scientific techniques, including genetic engineering, that are used to create, improve, or modify plants, animals, and microorganisms. Using conventional techniques, such as selective breeding, scientists have been working to improve plants and animals for human benefit for hundreds of years. Modern techniques now enable scientists to move genes (and therefore desirable traits) in ways they could not before—and with greater ease and precision (USDA, 1999).

Bt crops are genetically engineered to carry the gene from the soil bacterium *Bacillus thuringiensis*. The bacteria produce a protein that is toxic when ingested by certain Lepidopteran insects. Crops containing the Bt gene are able to produce this toxin, thereby providing protection throughout the entire plant.

Bt cotton is genetically engineered to control tobacco budworms, bollworms, and pink bollworms.

Bt corn is genetically engineered to provide protection against the European corn borer.

Cell is the smallest structural unit of living organisms that is able to grow and reproduce independently (ABA).

Genetic engineering, very broadly, is a technique used to alter or move genetic material (genes) of living cells. Narrower definitions are used by agencies that regulate genetically engineered organisms. In the United States, under guidelines issued by USDA’s Animal and Plant Health Inspection Service, genetic engineering is defined as “the genetic modification of organisms by recombinant DNA techniques” (7CFR340: 340.1), while definitions used in Europe are somewhat broader.

Gene stacking involves combining traits (e.g. herbicide tolerance and insect resistance) in seed.

Herbicide-tolerant crops were developed to survive certain herbicides that previously would have destroyed the crop along with the targeted weeds. With herbicide-tolerant crops farmers can use potent postemergent herbicides, providing a more effective weed control than otherwise. The most common herbicide-tolerant crops (cotton, corn, soybeans, and canola) are Roundup Ready (RR) crops resistant to glyphosate, a herbicide effective on many species of grasses, broadleaf weeds, and sedges. Other genetically engineered herbicide-tolerant crops include Liberty Link (LL) corn resistant to glufosinate-ammonium, and BXN cotton resistant to bromoxynil. There are also traditionally bred herbicide-tolerant crops, such as corn resistant to imidazolinone (IMI) and sethoxydim (SR), and soybeans resistant to sulfonylurea (STS).

Plant breeding involves crossing plants to produce varieties with particular characteristics (traits) that are carried in the genes of the plants and passed on to future generations.

Transgenic plants result from the insertion of genetic material from another organism so that the plant will exhibit a desired trait. Recombinant DNA techniques (DNA formed by combining segments of DNA from different organisms) are usually used to develop transgenic plants.

eties vary with those levels. Therefore, farmers in regions that have a higher probability of pest infestations would expect greater benefits in the form of reduced pesticide applications and higher yields.

This report first establishes a context for interpreting the results by presenting information about pest management on major field crops in U.S. agriculture and then summarizes previously reported studies of the effects on pesticide use, crop yields, and producer returns from using genetically engineered crops for

pest management. Next the report presents survey information obtained from USDA's Agricultural Resource Management Study (ARMS) about the extent of adoption of genetically engineered cotton, corn, and soybeans (by type of technology, crop, and region). The report then presents the results of an econometric analysis on the farm-level effects of adopting Bt cotton and herbicide-tolerant soybeans and cotton on pesticide use, crop yields, and net returns.

Environmental and Other Concerns

Although there are environmental benefits from using crops with herbicide-tolerant or insect-resistant traits, there are some concerns about extensive use of these crops. One concern is that herbicide-tolerant crops would foster farmers' reliance on herbicides.

However, these crops may require lower application rates or fewer herbicide applications. And, in many cases, these crops allow farmers to use more benign herbicides instead of more harmful ones and allow farmers to use them as postemergent herbicides. For example, glyphosate is considered to be environmentally benign (Culpepper and York, 1998; Roberts et al., 1998). There could also be risks to nontarget insect species if Bt crops deplete populations of prey species, but this is also a problem with many traditional pest management systems.

Another concern is that extensive use of these crops could lead to the development of insect and weed resistance. Since genetically engineered crops interact with the environment, concerns have been raised about risks associated with their release. One potential risk is that herbicide-tolerant crops may pass their genes to weedy relatives, thereby making those weeds resistant to herbicides (Rissler and Mellon).

Another risk is that Bt crops would promote insect resistance to Bt. Resistant insects could make crops more vulnerable. This problem exists with chemical pesticides as well, but Bt genetically engineered into a plant will persist in the environment longer than foliar Bt, thus shortening the time for targeted insect pests to become resistant to foliar Bt. Some agricultural producers, such as organic growers, rely on Bt for insect control, and, if insects become resistant, these growers could lose the option of using these products. However, the Environmental Protection Agency (EPA) requires resistance management plans to control insect resistance to Bt to ensure that

enough susceptible moths survive to mate with resistant ones (Cotton Insect Control Guide, 1997).

More recent concerns are related to popular press commentaries of a letter published in the May 20 issue of *Nature* (Losey et al., 1999) reporting results of laboratory tests showing that corn pollen of Bt corn killed the monarch butterfly larvae and recommending a comparison of "these risks with those of other pest-control tactics." However, several scientists noted that the popular press missed the subtleties of the research, and the lead author of the study recently declared that "it would be inappropriate to draw any conclusions about the risk to monarch populations in the field based solely on these initial results" (Wipf).

There are also concerns, especially in Europe, that foods with transplanted genes may cause allergic reactions. A gene from a nut inserted into another type of food, for example, might trigger allergic reactions in susceptible consumers (Panos). And some critics doubt that the body digests and assimilates biotechnology-derived foods in the same way as traditional foods. But the Food and Drug Administration (FDA) ensures that genetically engineered foods reaching the marketplace are "substantially equivalent" to current foods and pose no additional risk. The FDA would require a label for genetically engineered foods only if there were known risks, as with traditionally grown foods.

In addition, some believe genetic engineering interferes with "nature" and "creation." Scientists argue, however, that all plants are genetically modified ("that is what evolution means") either by natural selection from random mutations and recombinations, by domestic breeding, or more recently by "engineered mutation or recombination" (Panos).